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ANALYSIS OF OBSERVED SOIL SKIN MOISTURE EFFECTS ON REFLECTANCE.(U)

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ANALYSIS OF OBSERVED SOIL SKIN MOISTURE EFFECTS ON REFLECTANCE

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A light reflectance device has been applied to various soil surfaces, and the results have been correlated to independent measurements of skin moisture content. Results show that for the configuration used moisture effects are masked by those of surface texture. Modifications are recommended.

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CONTENTS

INTRODUCTION

Satellite measurements of cloud brightness and temperature are related to the meteorological phenomena within the cloud, including droplet formation, cloud thickness, and density. The brightness is a function of the interaction of the cloud with the incident radiation and the viewing angle of the satellite. Analysis of the cloud brightness properties must consider the angle of incident radiation and the observation angle, or the bidirectional reflectance. Such analysis is also frequently aided by observing the brightness of surface features adjacent to clouded regions in the imagery. For that reason, a number of reference sites with particularly useful optical properties are of interest to analysts. One such site is the gypsum deposit at White Sands Missile Range (WSMR) NM, where the Atmospheric Sciences Laboratory (ASL) maintains a permanent calibration station for measuring surface radiance, sky radiance, air temperature, and relative humidity.

Earth reference calibration of satellite sensors requires that the bidirectional properties of the calibration site be known. The WSMR calibration site was determined to have relatively uniform reflective properties when dry but to deviate considerably from a lambert surface when moisture is high [1-3].

OBJECTIVE

The purpose of the tests described here was to evaluate progress to date in the development of an instrument that can be used to determine the reflectance properties of the calibration surface as it is affected by moisture in the soil skin layer and to measure the surface texture and its structural properties.

The prototype soil skin reflectometer was evaluated under field conditions for convenience of operation and reliability in the determination of the surface reflectance. The instrument was tested on three surface soil types at several soil moisture levels and the bidirectional reflectance compared with measured soil moisture for each surface type.

INSTRUMENT DESCRIPTION

The reflectometer consists of an optical assembly, power supplies, and strip chart recorder. The power requirement is nominally 20 W at 110 V 60 Hz. The optical assembly contains a 1.0 mW helium neon laser (Coherent Radiation Inc., Model 80), a photodiode detector, two mechanical choppers, and associated optics. These components are mounted in a rigid framework so arranged that the laser beam is incident on a horizontal sample plane flush with the base of the assembly, the angle of incidence being 60° from normal. The beam is chopped at a 90 Hz rate by the mechanical chopper in front of the laser and reflected down to the

sample plane by a mirror at the front of the optical assembly. A diverging lens expands the illuminated spot to approximately 2 by 3 cm in the sample plane.

The detector views this illuminated area at an angle of 60° from normal, its field of view being approximately four times the area of the laser spot. A second chopper in front of the detector blocks the entrance window for a 10-second period at 60-second intervals for reference purposes. During this period the laser beam is reflected from the rear of the chopper surface to the detector to give a measurement of its output power.

During the 50-second measurement interval, the signal produced by the chopped reflected light is detected by a phase-locking amplifier, rectified to a DC voltage (0-100 mV) and displayed on a strip chart record. The DC level on the record is then proportional to the amount of light diffusely reflected by the material at the sample plane.

METHODS AND TEST PROCEDURES

Tests were conducted on 29-30 July 1976 at WSMR. The tests were conducted by ASL personnel and contractor design and development personnel. The individuals directly involved included CPT S. E. Taylor, CPT J. M. Davis, and Mr. James Mason of ASL, and Drs. I. Dirmhirn and N. N. Youssef of Utah State University.

The prototype sensor assembly (Fig. 1) houses the laser radiation source and the scattering detector. The assembly is easily transportable and is intended for use on relatively flat surfaces. The assembly has skid supports designed to place a portion of the surface in the intersection volume of the optical system.

The prototype system (Fig. 2) is powered by 110 V, 60 Hz line supply or by mobile power supply. Both power modes were used in the test. The system includes the sensor assembly, electronics and interfacing components, and recorder output components. The configuration of the system will be altered somewhat by miniaturization of the electronics and interface package in the delivered unit.

The test conditions included:

1. Three soil surface types

2. Soil moisture content - field dry to ponded water

3. Angular effects (sloping test surface)

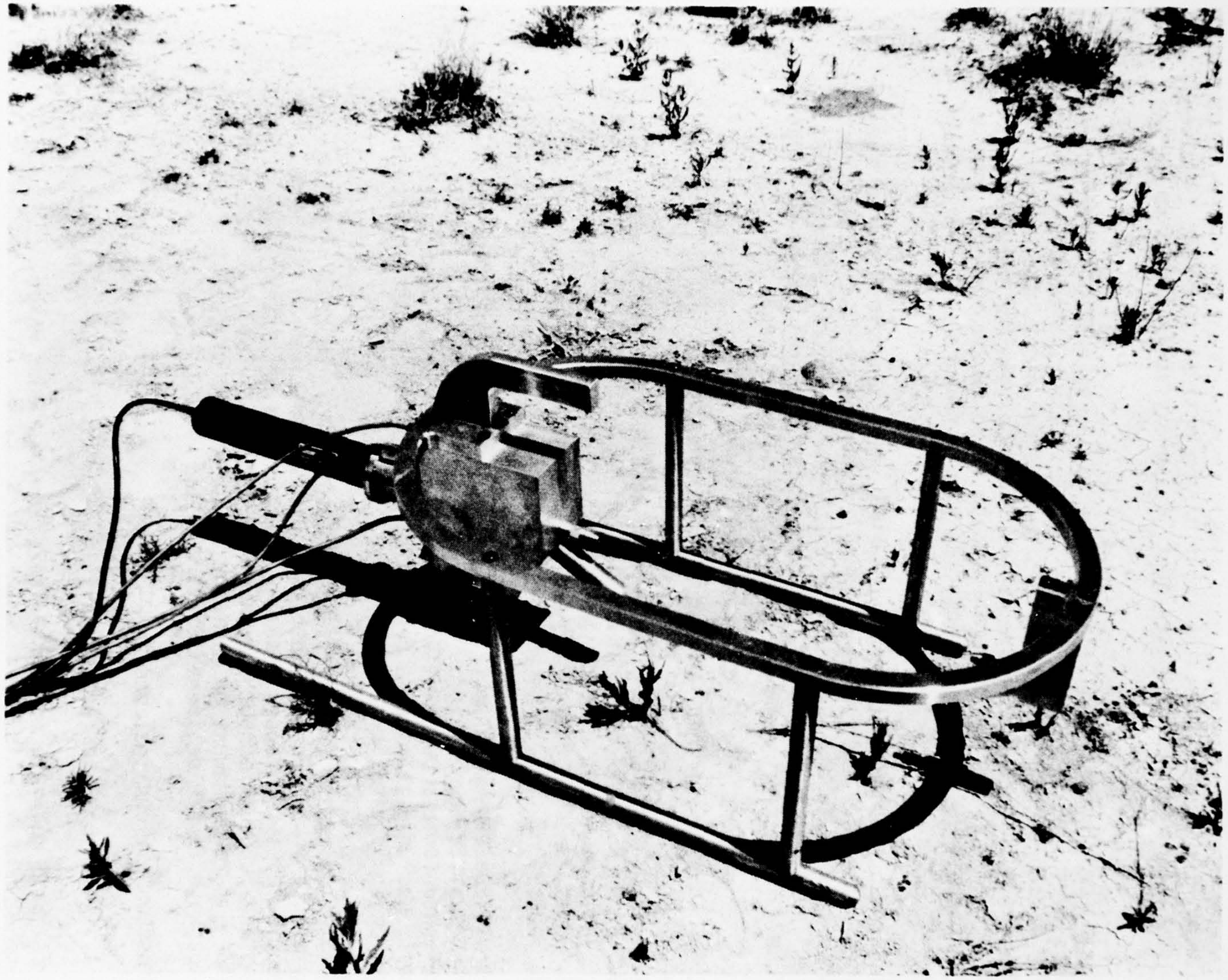

Figure 1. Sensor assembly for soil skin moisture determinator. The moisture at the soil surface affects the quantity of light from the laser source which is received by oblique scattering at the detector.

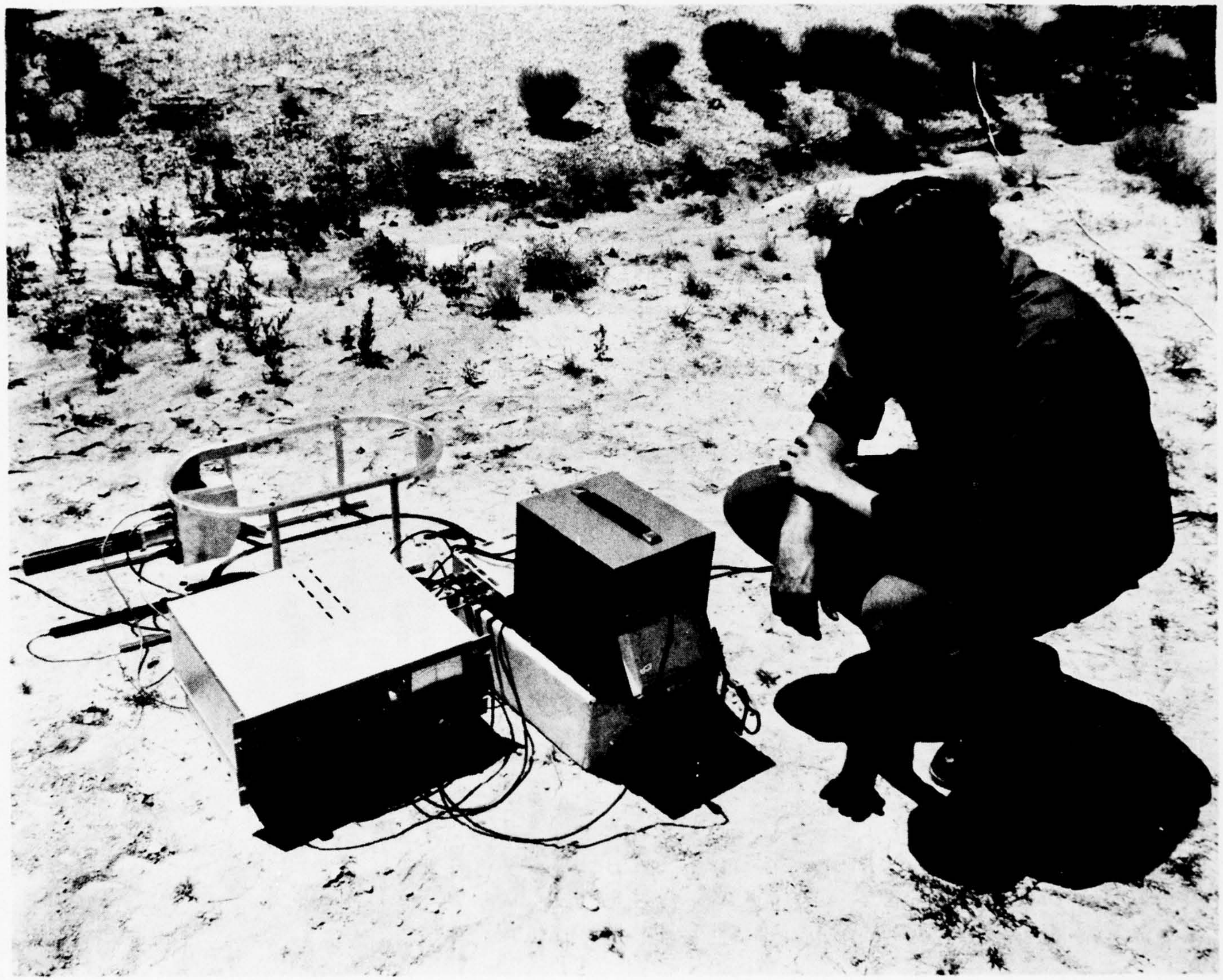

Figure 2. Sensor assembly and electronics package for soil skin moisture determinator. The sensor assembly and recorder will be little modified in operational system. The electronic amplifier is intended *for development and will be replaced by a miniaturized component.*

The three soil surface types tested were dunes of wind deposited gypsum sand, playas or flat areas resembling dry lake beds where the water table is shallow and the surface has been encrusted, and soil composed of siliceous sand. The reflectance measurements were made on 29-30 July 1976 during midday, and soil moisture was determined from surface sample collected at the sites and delivered to the laboratory.

In addition to the macroscale topographic variation mentioned above, each site exhibited a variety of microscale topographic features which ranged from a smooth fine sand surface to areas characterized by small pebbles (1-2 mm in diameter) and sand ripples. The instrument was particularly sensitive to the microscale topographic features.

Soil samples were taken from the surface layer to a depth of 1/2 cm; the material was then weighed, dried for 24 hours at 113°C, and reweighed. The moisture percentage of the soil was defined as the weight of water in the sample divided by the weight of the soil and water in the sample.

The reflectometer is most sensitive to moisture right at the surface, and considerable variation in soil reflectance measurement was anticipated because of the potentially large moisture difference between the top millimeter and the fifth millimeter of soil.

Field capacity is reached after a soil, which has been completely saturated, has drained under the force of gravity. A soil is said to be saturated when all the pore spaces in the soil are filled with water. Soils in this study were saturated by ponding water on the surface.

While the human eye judged the darker sand to be substantially wetter than the light color sand, gravimetric analysis of the soil samples indicated very little difference in the soil moisture content from one location to the next (see Table 1). The range of values was from 11.8% to 14.3%. These results indicated that light sand areas were actually relatively wet just below the first millimeter of surface sand crystals. In the following paragraphs, the results at each site will be discussed and analyzed.

Alkali Flats (Playas)

The soil moisture-reflectance dependence on the alkali flats was determined on the basis of two sample sites. Table 2 contains the alkali flat data. The soil moisture content at each site was found to be approximately 14%; however, the reflectance values (in percentage of scale) ranged from 16.7% to 63.5%. All samples were taken within a few inches of each other.

TABLE 1. GROUND TRUTH DATA SHEET IV

Soil Moisture Analysis

	A. Dish Weight (gm)	B. Wet Sample and Dish Weight (gm)	C. Wet Sample Weight (gm) (B-A)	D. Dry Sample and Dish Weight (gm)	E. Dry Sample (gm) (D-A)	F. Moisture Weight (gm) (C-E)	G. Moisture (%) (F-C)
Siliceous Sand Site							
Dry sand	38.240	39.903	1.663	39.829	1.589	.074	4.4
Dry powder	33.922	39.365	5.443	39.192	5.270	.173	3.2
Wet sand	36.330	41.360	5.030	40.387	4.057	.973	19.3
Gypsum Sand Site							
Flat	34.021	47.248	13.227	45.402	11.381	1.846	14.0
Flat	25.932	40.920	14.988	38.868	12.936	2.052	13.7
Dome	32.374	46.195	13.821	44.286	11.912	1.909	13.8
Dome	29.010	43.404	14.394	41.433	12.423	1.971	13.7
Dune top	38.157	53.936	15.779	51.806	13.649	2.130	13.5
Dune top	36.314	52.138	15.824	49.872	13.558	2.266	14.3
Dune valley	33.900	53.436	19.536	51.123	17.223	2.313	11.8

TABLE 2. ALKALI FLAT

Site 1		Site 2	
Sample	Reflectance	Sample	Reflectance
A	64.3	A	48.9
B	16.7	B	46.1
C	23.9	C	54.0
D	35.5	D	63.5
E	19.2	E	49.1
F	59.0		
G	29.4		

Soil moisture content at site 1: 13.9%

Soil moisture content at site 2: 13.8%

The soil moisture value given for site 1 is an average of soil moisture percentages obtained from samples B and E (14.0%) and F (13.7%). On the basis of visible observation, B and E were assumed to be wet, while F was assumed to be dry. The gravimetric analysis shows that this visual observation was incorrect. It is important to note that the reflectance values at B and E averaged near 18% while at F the value was 59%. Evidently, some factor other than soil moisture was having a major effect on the reflectance. This factor was the microscale topographic feature of the area. The reflectance values at site 2 were more uniform than at site 1, and the soil moisture was nearly the same. Areas which were rough tended to have a lower reflectance.

Alkali Dome Structure

The dome structure has no appreciable relief on the alkali flats. The structure may be below other features which originate from deposits of blown sand. The dome is an area of deposition from subsurface upwelling of water and solutes. The dome areas are often crusted, normally moist, and darker in color, and often contain a black or greenish appearing layer.

The soil moisture content on the dome structure was 13.5%. Reflectance values ranged from a low of 18.5% to a high of 51.0%. The data are contained in Table 3.

TABLE 3. ALKALI DOME

Sample	Reflectance
A	36.0
B	42.0
C	18.5
D	32.5
E*	45.5
F*	51.0
G*	42.4
H*	50.7

Soil moisture content: 13.5%

*Laser beam incident direction changed by 90°

After an initial series of readings on the dome structure, the laser housing was rotated so that the new beam direction was perpendicular to the old beam direction. No significant differences in the reflectance readings were noted.

TOP OF A GYPSUM DUNE

The sand dune provided a unique setting in which to study the microscale topographic features. The top of the dune was covered by small waves or ripples in the sand which were about 10 cm in wavelength and 1 to 2 cm in height above the sand surface. The laser was used to obtain reflectance values both parallel and perpendicular to the ripples (Fig. 3). The data are contained in Table 4.

The soil moisture content of the dune top was 14.3%. The reflectance measurements taken parallel to the ripple pattern exhibited the highest values (53 to 55) at the crest of the ripple. Lesser values (26.0 to 33.2) were obtained on the slopes. These lesser values were most likely the result of the geometry of interaction between the slope and the beam.

When the laser beam was directed perpendicular to the ripple pattern, reflectance values on the ripple crest and on the windward slope were approximately equal. However, on the steep or lee slope the reflectance values were somewhat lower (43.7). Again topography was probably the critical item.

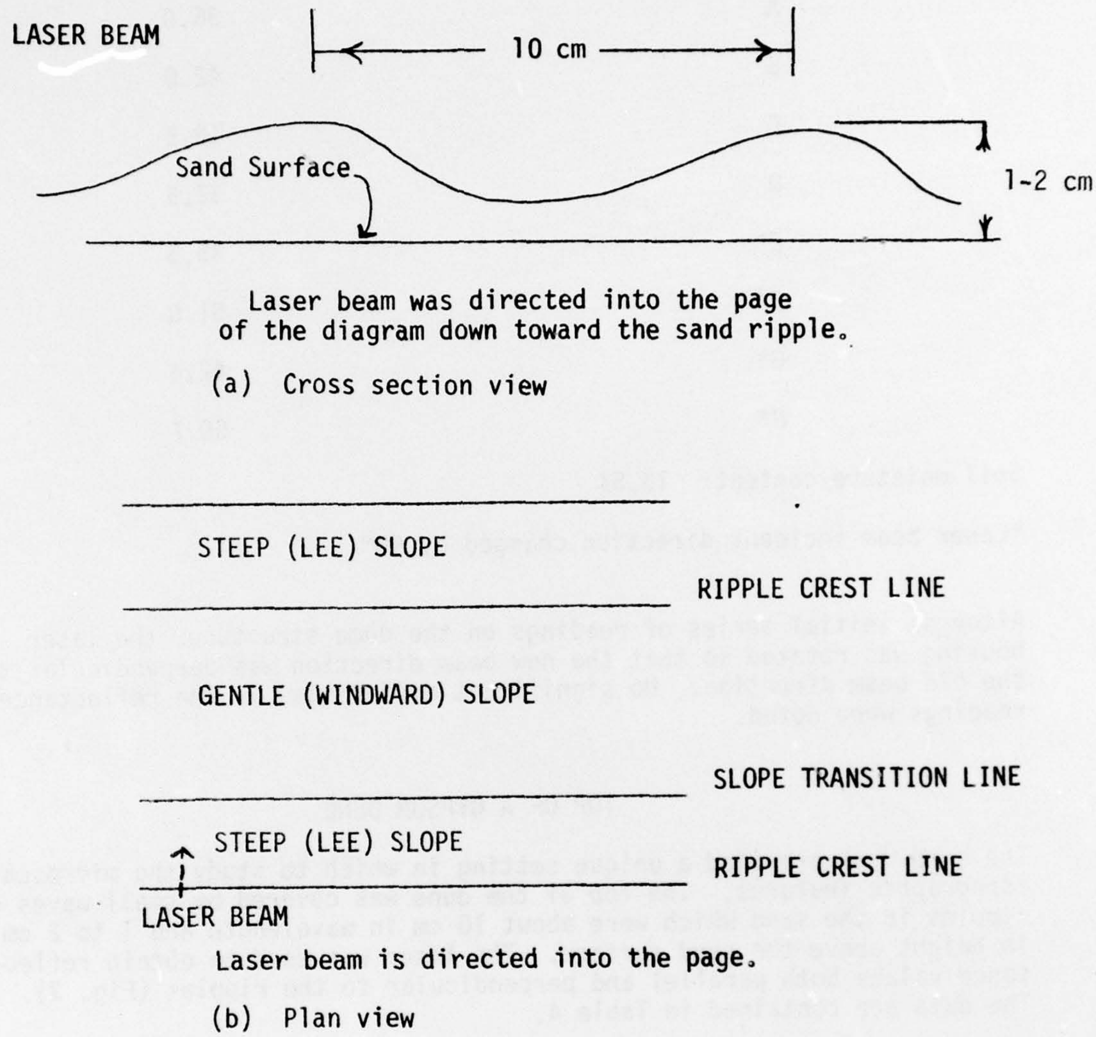

Figure 3. Illustration of ripple structure.

TABLE 4. SAND DUNE TOP

Sample	Reflectance
A*	54.3
B	26.5
C	32.9
D	54.3
E**	54.5
F**	58.8
G**	43.7
H**	58.1

Soil moisture content: 14.3%

*Laser beam parallel to the ripple
**Laser beam perpendicular to the ripple

VALLEY BETWEEN DUNES

In the area between the dunes, the soil moisture content was 11.8% (Table 5). Reflectance values ranged from 26.3% to 28.7% in the first test sequence. When the direction from which the beam was coming was changed by 90°, the reflectance values increased (43.2% to 54.2%). The change in reflectance values would again seem to be the result of the soil crystal deposition pattern. The initial readings were taken with the general slope of the area and the final set with the contour; hence, a deposition pattern difference was likely although not apparent to casual inspection.

TABLE 5. VALLEY BETWEEN DUNES

Sample	Reflectance
A	28.7
B	28.7
C	28.7
D	26.4
E*	43.4
F*	53.9
G*	53.9

Soil moisture content: 11.8%

*Laser beam incident direction changed by 90°

DISCUSSION

Reflectance values range from a value of 16.7% to 63.5%, while soil moisture values range only from 11.8% to 14.3%. This difference in range would seem to indicate that reflectance characteristics cannot be determined from soil moisture status alone. Here the major influence on the reflectance is the microscale topography of the site. Therefore, it is clear that some alternate method should be used to test the laser's ability to characterize the bidirectional reflectance from a surface.

The effect of ponded water on the laser beam was also investigated. Enough water was poured on a sandy surface to cause ponding followed by the rapid infiltration of the water into the sand. The ponded water surface caused the specular reflectance of the laser beam to give an off-the-scale reflectance reading. After infiltration had taken place, the surface became a diffuse reflecting surface and the reflectance values were quite low. As the surface dried, the reflectance values slowly increased. Thus, under saturated conditions, for example, immediately following rain while relative humidity is still high, reflectance is expected to be near 0. Values would then rise as the surface dried.

An additional test was performed on a siliceous soil under dry (soil moisture content 4.4% and 3.2%) and wet (soil moisture content 19.3%) conditions. Three sites were observed. The sites were chosen so that the microscale topographic features of all three were as identical as

possible. The laser showed a marked response to the change in soil moisture status (Table 6). Thus when surface topographic variations can be eliminated, the laser has the ability to characterize changes in the bidirectional reflectance that result from changes in soil moisture content.

TABLE 6. WET AND DRY SILT SURFACE

Sample	Percent Soil Moisture	Reflectance
Dry dirt	4.4	90
Dry powder dirt	3.2	42.6
Wet dirt	19.3	12

ACCEPTANCE TESTING

If the bidirectional reflectance depended primarily on the soil water content, the above approach might have greater utility; however, the results of the present tests indicate that surface morphology is the controlling factor. The characteristics of surface morphology are not easily described and make solution of the problem much more difficult.

An alternate method of evaluating the suitability of the instrument according to the government requirement for bidirectional reflectance measurements should be incorporated in the final acceptance testing. A possible method would be to make real-time comparison of the reflectometer with a satellite-type narrow view radiometer. The test should include measurements at several solar incidence angles and appropriate radiometer view angles.

A satellite-type radiometer should be placed approximately 15 to 20 feet above the ground, making an angle with the local vertical which would mimic the satellite viewing angle (Fig. 4). This fixed angle radiometer would be used to record solar spectral reflectance as the sun changed elevation angle. The laser should be checked coincidently against the data obtained using the radiometer. The return beam optic could be adjusted in such a way to also mimic the satellite view angle. To model the changing sun angle the laser source could be designed to move along a rod horizontal to the ground. A comparison of the radiometer data and laser signal output data could be utilized to assess the ability of the portable laser system to model the bidirectional reflectance of a surface. It is felt that such a testing procedure performed on the white sand would be a relatively conclusive means of evaluation. This testing procedure would require that the reflectometer be configured to allow adjustable scattering detection angles or that a mathematical method be provided

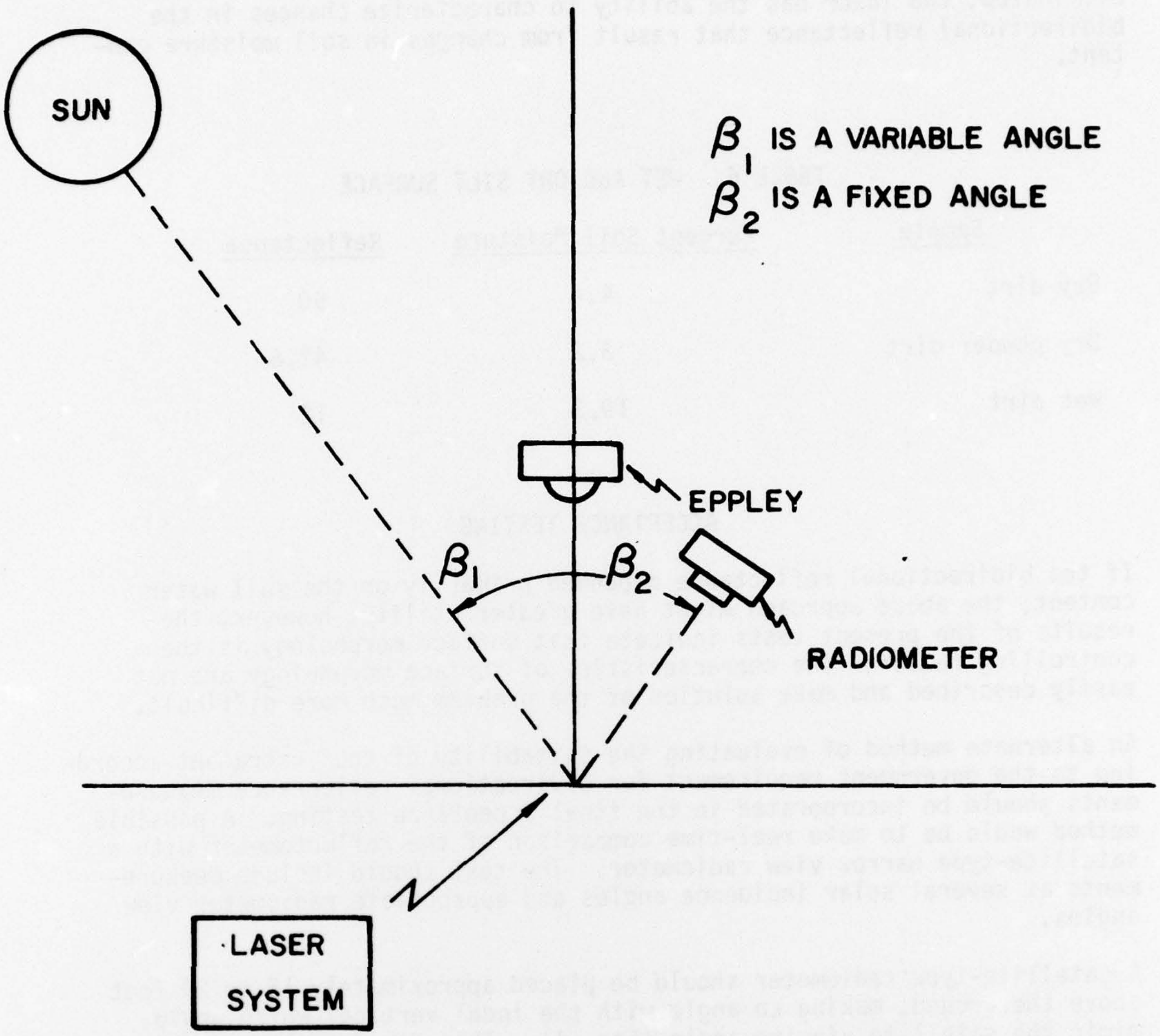

Figure 4. Experimental arrangement to test the laser system against a satellite-type radiometer.

which would accurately describe the scattered energy at angles other than the fixed reflectometer detection angle. Additionally this testing would require that a narrow view, satellite type radiometer be available for the evaluation acceptance testing. It is also necessary in the final testing procedure to determine how many readings must be made with the laser to characterize the bidirectional reflectance of a surface.

CONCLUSIONS AND RECOMMENDATIONS

This test showed that the reflectometer can measure the bidirectional reflectance if the surface is suitably chosen or the method of performing the measurement is so designed as to integrate effects of microscale structure in determining surface measurements.

The following findings were made:

1. The instrument is satisfactory for measurement of soil moisture in the skin layer if the surface is prepared by a flattening technique and calibration has been accomplished for the particular soil.

2. The instrument is sensitive to surface morphology and moisture content.

3. The bidirectional reflectance values should be tested against an established bidirectional measurement technique rather than compared only with gravimetric soil moisture content.

4. The sensor assembly probably should be fitted with an indicating device to show operators the precise area sampled. A ring positioned near the soil surface is suggested.

5. The delivered product should have a single electronic package/interface and the components should be connected by single cables.

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